Attorney Docket No. 3123-321

METHOD AND APPARATUS FOR PROCESS TESTING A DISK DRIVE

FIELD OF THE INVENTION

The invention described herein relates to an apparatus and method for performing manufacture test processing for disk drives, and more particularly to a method and apparatus for performing manufacture test processing on disk drives outside a factory setting while the disk drive is functioning in a computer system.

BACKGROUND OF THE INVENTION

Most computer systems include a memory storage device such as a hard disk drive for storing large amounts of data. Most hard disk drive units typically include a magnetic disk that is configured to store a large amount of binary information. This magnetic disk is typically coupled to a hub that is rotated by an electric motor commonly referred to as a spin motor. In order to read information from the disk, a head is employed which magnetizes and senses the magnetic field of the disk. The head is typically located at the end of a cantilevered actuator arm that can pivot about a bearing assembly mounted to a base plate in the disk drive. The actuator arm has a coil which cooperates with the magnet mounted to the base plate. Providing a current tube coil creates a torque on the arm and moves the head relative to the disk. The coil and magnet are commonly referred to as a voice coil motor or VCM.

Hard disk drive units contain a number of integrated circuits that control the operation of the drive. The circuits typically include a read/write channel that is coupled to the transducers of the actuator arm assembly. The read/write channel connected to an interface controller which is

coupled to the host computer. The interface controller is coupled to a random access memory (RAM) device that is used as a buffer to store data transferred between the disk and the host.

An essential component to operating of the memory storage system is the magnetic disk. Typically data is recorded on the disk in the form of magnetic transition spaced closely together. In modern disk drives in particular, recording densities both in terms of ratio tracks per inch and linear density along a track have reached a level which creates extreme sensitivity to imperfections in the disk these imperfections are known as media defects, and occur in the magnetic recording layer. These defects which results in portions of the layer becoming unacceptable for use in recording the magnetic transitions. Media defects may be small, affecting only a small number of transitions on a small number of tracks, or large, affecting many transitions across multiple tracks.

SUMMARY OF THE INVENTION

In order to detect media defects, a number of manufacturing tests processes may be performed on a disk drive at the factory prior to its installation in a computer system. These tests may include flaw mapping, wherein a write/verify process is performed over each of the radial tracks to identify logical block addresses (LBAs) which possess defects and may not able to receive and store information. The locations of LBAs with defects which are discovered during flaw mapping may be then stored in a flaw map for the disk. Other tests which may be performed include runout compensation which checks and then provides corrections for irregularities in the shape of the tracks (cylinders), as well as final drive verification.

The performance of these manufacture test processes may a be very time consuming process. As such, the inventor has recognized that disk drives may be designed such that instead

of having the manufacturing test processes performed in the factory prior to installation, a number of tests may be automatically performed by the disk drive once it is activated and operational in a computer system.

Described herein is a method and apparatus for performing automated manufacture test processes on disk drives once the disk drive is installed and operating within a computer system. The system described herein may be configured as a processing module which is locatable in a memory for the disk drive, where memory for the purposes of the system described herein may include any sort of information storing device, such as a processed portion of the disk drive, a random access memory, and a read only memory (ROM), as well as any combination of these devices. Included in the processing module may be sequences which are employable to perform a number of automated tests. The test procedures and other saved information is retrievable by the processor of a disk drive such that the testing may be performed at predetermined times.

In one aspect of the invention, the test to be performed may include at least one of: flaw mapping, runout compensation, as well as final verification pass. The performance of the flaw mapping may include initiating write/verify tests of LBAs on the recording media during either during normal write commands for the disk drive, or during periods of time when the computer system is in an idle mode. More particularly, the flaw mapping module may be configured such that an initial query may be made as to whether any user commands are pending. If a write command is pending, an analysis may be made as to whether the addresses to which information are to be written are LBAs which have been previously processed. If not, during the write function to these LBAs a verify may be performed to determine whether the information was stored correctly. If it is determined that information was not stored correctly, the LBA may be reassigned to a processed area of the disk and a pointer provided at the original location to direct

all future read and write functions to the new location. As LBAs are processed, various counters may be are employed and continually updated and saved to track which of the LBAs have been processed. The processing module is further configured to determine when a write function is to perform in an area which includes both processed and unprocessed LBAs. The processing module will perform write functions to processed areas and then perform write/verifies on the unprocessed area before information is permanently written to a particular LBA.

In the situation where there are no user commands pending and the computer system is an idle mode, the processor may be configured to perform the write/verify tests on LBAs using test information. As an initial step, information may be retrieved from memory which indicates which of the LBAs have been tested and which have not. Once the next unprocessed LBAs are identified, the write/verify functions are performed and all the LBAs which have flaws are reassigned to a processed area of the disk and pointers provided at the previous location. Once a particular increment of LBAs is processed, a pointer may be updated and a check made as to whether any user commands are pending.

A further test performed by the automated system may include runout compensation. Unlike the flaw mapping, runout compensation typically is not performed when a user command is being performed or pending. This test is performed during idle times and an error signal is generated which may be stored in memory which provides a correction for the read/write heads of the disk drive. An initial query which may be made as to whether a user command is currently pending. If there is a user command pending, it is performed and the runout compensation test will not be performed until there is a detected idle time. If an idle time is detected, at least one counter is accessed from memory to identify which of the cylinders is next to be processed. To track the completion of the runout compensation, various counters are

maintained which indicate which cylinders have been tested and which have not. Further, various schemes may be established such that various cylinders may not be employed during normal operations of the disk drive until at least one adjacent cylinder has also been tested. Separate pointers may be employed to track both of these items.

Once the next cylinder to be processed is identified, the runout compensation for that cylinder is performed and an error signal generated and stored in memory. Further all the counters employed to track which cylinders have been processed are updated and stored in memory. Another query may then be made as to whether there are any user commands pending. If there are, those commands are performed, if not, another cylinder is tested until all unprocessed cylinders are processed.

In order to ensure that all the LBAs which were tested are not flawed, a final verification pass may be made. As with the test described above, this test may be automatically initiated either during idle times or performed in conjunction with write functions performed as part of user commands. If the final verification is performed as part of a user command, previously saved counter information is accessed and employed to determined whether the final verification has been performed previously on any of the LBAs to which a write is to occur. If not, the write function is performed on the LBAs and the information is verified. If any errors are detected, the LBAs are reassigned and a pointer is generated to direct all future write functions to the reassigned LBAs. Once the write function is complete, the necessary pointers are updated and a further query is made as to whether any user commands are pending.

If the computer system is in idle, the counter information is retrieved from memory and a increment of LBAs are identified for which the final verification test is to be performed. At this point, the information stored on these LBAs is read and verified. If any errors are detected, the

effected LBAs are reassigned and a pointer is included in the media. At this point, the counters are updated and the system returns to its initial query.

In one aspect of the invention, portions of the test described above may be performed at the factory prior to the disk drive being installed in the computer in order to detect any major flaws which may exist in the disk. For example, a certain percentage of the LBAs and cylinders at designated locations on the media may be tested so as to identify any major flaws which may extend across multiple LBAs or cylinders

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 discloses a top view of a magnetic disk in a disk drive along with an actuator arm.

Figure 2 discloses an electronic system diagram for the disk drive.

Figure 3 discloses a flow chart which describes the steps performed for a write/verify function during flaw mapping of a disk drive.

Figure 4 discloses a flow chart which describes the steps performed by the disk drive during automated flaw mapping operations.

Figure 5 discloses a flow chart which describes the steps performed by the disk drive during automated runout compensation testing.

Figure 6 discloses a flow chart which describes the steps performed by the disk drive during automated final drive verification.

DETAILED DESCRIPTION

Disclosed in Figure 1 is a disk drive 10 configured in accordance with the present invention. The disk drive 10 includes a disk 12 that is rotated by a spin motor 18. The disk 12 may be constructed from a metal, glass, ceramic or composite substrate that is covered with a magnetic coating as is known in the art. The disk 12 rotates relative to an actuator arm assembly 13 which has a pair of transducers 15, commonly referred to as heads. The transducers 15 contain a coil (not shown) which can magnetize and sense the magnetic field of each corresponding adjacent surface of the disk 12. Each head is supported by actuator arm 13. At the opposite end of the actuator arm 13 from the transducer heads 15 is the voice coil motor 16. Connections run from the voice coil motor to the various electronics of the system. The voice motor coil 16 is employed to rotate the actuator arm and transducers such that the transducer heads may be positioned in the appropriate positions in order to read or write information on the disk 12.

Data is typically stored on a magnetic disk 12 along annular tracks concentric with the diameter of the disk. The disk may be any number of sizes which includes an 1.8", 2.5", 3.5", etc., diameter disk. For example, with a 1.8 inch disk, the system will typically store data on a 130 tracks per disk surface. Each track contains a plurality of servo sectors in one configuration of the invention. Each sector is capable of storing up to 768 bytes of data. The total assembly is capable of storing up to 130M of data.

Figure 2 shows a schematic of the electronic system architecture of the hard disk drive assembly 10. The system includes a data manager 28 which provides for the data exchange between the disk drive and the host computer system. In connection with the data manager is the controller 30 which provides control signals for the various electrical components of the hard

drive. Connections are established from the controller 30 to a number of components such as servo 20 which controls the operation of the voice coil 22 and the spin motor 24. Further connections are established from the controller to read only memory (ROM) 34 upon which software which the drive employs to run may be stored. The read/write (R/W) chip 32 controls the read/write functions for data stored on and received from the disk through pre-amp 36 and pads 38.

In operation, the disk drive is installed in a host computer system. The disk drive electronics may receive a request from a host 26 for reading or writing data on the disk. The data manager 28 will receive the requests from the host in the form of a logical block address (LBA). This information is provided to the controller 30 which in turn converts the logical addresses to physical disk addresses. The controller chip 30 may then initiate a seek routine through the servo 20, which in turn moves the heads to the proper location on the disk. When the voice coil has moved the transducer to the desired disk sector, the controller chip provides a z-sector signal to the data manager. Upon receiving the z-sector signal, the read or write function may be initiated and the necessary functions performed using the R/W chip 32 pre-amp 36 and the heads 38. The data extracted by the R/W chip 30 max then be provided through the data manager to the host computer 26.

To ensure that the disk drive is able to operate in a computer substantially as described above, a number of manufacturing tests processes may be performed on the disk drive. Typically, the manufacturing test process are performed at the factory prior to installation of the hard drive in a host computer. According to the invention described herein, while a number of tests may be performed prior to installation of a disk drive in a computer system, a number of

these manufacturing test processes may be performed while the disk drive is installed and operating within a host computer system.

As is known, flaws on a disk in a disk drive will affect its performances. Defects to areas of the disk will make it so that reading and/or writing of information to these areas of the disk is not possible. In order for a disk to operate properly, these defects are identified and appropriate pointers placed on the disk such that the information may be read or written to another area on the disk which is without defects this is know as flaw mapping.

Another issue which may affect the ability to read and write information on a disk relates to maintaining the read/write heads in alignment relative to the center of the continuous track on which information is stored or to be stored. Problems may arise in that the axis of rotation of the disk is not precisely the same as the center of the concentric tracks located on the disk or, a slight deviation was created with regards to one of the concentric tracks during the manufacture of the disk such that it temporarily moves out of its circular shape with regards to the axis of the disk. In operation, these areas should be compensated for such that the tracking of the read/write heads may be varied when information is to be written or read on this particular area of the disk. Compensation for these rotation problems is known as runout compensation.

Other tests which may be performed include drive verification which checks the mechanical aspects of the drive, servo optimization through which calibrations of the mechanical aspects and the head locations may be performed, data optimization wherein certain calibrations are performed and tolerances determined with regards to the different components of the disk drive.

As described above, the test for embedded run-out compensation, flaw mapping, and drive verification may be performed prior to the installation of the disk drive in a computer

system at the factory. However, as the number of tracks in a disk drive has increased, the total number of passes made at each location in performance of the above described tests has increased which in turn increases the production time required for the manufacture of the disk drives. According to the invention described herein the disk drives may be configured such that a number of manufacture process testing may be performed once the disk is installed in the host computer.

The disk drive described herein, is equipped with the functionality to perform a number of automated self test procedures. In the embodiment described herein, the self test procedures encompass embedded run-out compensation (ERC), flaw mapping, and drive verification. One skilled in the art would realize that any number of tests may be performed in an automated fashion while the disk drive is installed and operating in a computer system. The steps performed in those tests also fall within the scope of the present invention.

During the manufacturing of the disk drive, a number of tests such as drive functionality and data optimization may be performed at the factory. Additionally, flaw mapping, ERC, and final verification may be performed over a limited area over the disk to assure that there are no major flaws in the disk, and a at least a portion of the disk is processed and ready to store data once the computer system is operational. As an example, at the factory flaw mapping and ERC may be performed for the first 10 percent of the LBAs. The drive would then be flaw mapped and ERC performed for every N tracks of the remaining disk surface to assure that there are no very large defects and to be able to predict the total number of defects. A processed pointer may then be initialized and stored on the media indicating the portions of the drive that have been already processed. Also during the manufacturing process, an automated test program described in detail below may be written into memory, where memory for the purposes of the system

described herein may include any sort of information storing device, such as a processed portion of the disk drive, a random access memory, and a read only memory (ROM), as well as any combination of these devices.

Once the manufacturing testing processes performed at the factory are complete the disk drive may be installed in a computer system. According to the invention described herein, the unprocessed portions of the disk may be automatically processed during normal operations of the computer system. In particular, this automated processing may occur during write functions to unprocessed areas of the disk and during disk drive idle time (no user commands pending). This testing is substantially interruptible so as to not significantly reduce the performance of the disk during user commands for read and write functions during normal operations.

As was described above, some tests which maybe performed during normal operations of the computer system include flaw mapping, embedded runout compensation, final verification. As part the flaw mapping and final verification write or read/verify tests are performed which basically conclude whether a particular LBA is able receive and data when written to. Disclosed in Figure 3 is a flow chart which describes in the steps performed during a write/verify test which is employed by the automated test procedures described below. As an initial step a list of LBAs to be analyzed is identified. The first LBA in the list is identified and the test procedure begins with test information being written to the LBA. The LBA is then read and the information read from the LBA is compared against the test information. A determination is then made as to whether the read information is identical the test information. If any differences in the information read from the LBA are detected, a determination may be made that the particular LBA is flawed. If so, the LBA is re-assigned to another area on the disk and a pointer placed on the disk indicating the new location for the LBA .

If the information read from the LBA matches the test information, the LBA is determined to be functional and this may be updated in the flaw map for the disk. At this point the next LBA in the particular increment may be tested, and the flaw mapping continues until all LBAs in the particular increment are tested.

The flaw mapping process described above is employed as part of the automated flaw mapping procedures for disk drives which described herein. Disclosed in Figs. 4a and b is a flow chart which describes in detail the steps performed by the automated flaw mapping process once a disk drive is installed in a computer system and the computer system is operational. As an initial step not shown in the flow chart, at start-up of the computer, the processor for the hard drive may issue instruction to execute a software program, which is either stored on the disk or in ROM, to perform the automated tests. Once this software program is loaded and running, the system is ready to initiate the automated self test. As a first step, a query is made as to whether a user command is currently pending. User commands are instructions which direct the disk drive to read or write information on the magnetic media of the disk drive. If there is a user command pending, a determination is made as to whether it is a read or write command. If it is a read command, disk drive operations will proceed normally. If a write command is detected, a determination is then made as to whether the LBA's to which the information is to be written are in a processed or unprocessed area of the magnetic media. When the disk is delivered from the factory, certain areas of the disk may already be flaw mapped and this may be recorded on a flaw map for the disk drive which is accessible in memory. Further, as different areas of the disk are processed through the flaw mapping process, this is indicated in the flaw map.

Returning again to Fig. 4a, if the entire area which information is to be written is unprocessed, the disk drive will perform a write of the information and then a verify of what's

been written. If the write/verify step fails, a reassignment of the LBAs which failed is performed, the information is written to a processed area of the disk, and a pointer is placed on the disk which identifies the location of the reassigned LBAs. The pointer also indicates that the flawed area of the disk should not be used.

If it is determined during the write function that a first portion of the data is to be written to an unprocessed area and a second portion is to be written to a processed area, a write is initially performed to the processed area. With regards to the unprocessed area, the write/verify test is performed for the LBAs included therein. If the verify fails, there is a reassignment of the LBAs to new locations on the disk and a pointer is provided which redirects all future reads and writes to the new LBAs. In the last scenario, a determination may be made that the write is being performed to an area which has been all processed. In this case, there is no need to perform an automated test and the write function is performed normally.

In order to track the progress of the testing, a number of counters are incorporated in the automated test program. One counter is the process LBA counter which provides an indication of the last LBA which was processed. During various cycles of the program described herein, counters are continually updated in the case of interruptions due to user commands or power losses.

The system described herein is designed to perform the automated tests until the entire disk has been analyzed. As such, the automated program is further configured to test areas of the disk drive during detected idle times. Returning to the initial steps of the flow chart in Fig. 4a, if it is detected that there is no user commands pending, the automated self test disclosed in Fig. 4b may then be initiated. Initially, a counter saved in memory may be accessed to make a determination as to the last increment of LBAs to be processed and to identify the next increment

of LBAs which may be processed.. The number of LBAs included in an increment may be limited so as not to take enough time to unduly interfere with normal operations of the computer system. During the time that this automated process is being performed the disk drive may be inaccessible.

Returning again to the flow chart of Fig. 4b an additional query may be made as to whether there are enough LBAs left to be processed for a normal processing increment. If there enough LBAs for an increment, a test information is retrieved and employed in a write/verify step for each LBA. Any LBAs which fail the write/verify test are reassigned and a pointer is provided on the disk. Once all the LBAs in an increment are tested, the defect map stored in memory is updated as well as the counter which indicates which LBAs have been processed. Another increment of LBAs will be identified and tested unless a new user command is detected or there are no more LBAs left unprocessed.

In the situation where there is not a normal increment of LBAs for performing the automated processing, the remaining unprocessed LBAs are automatically tested and the defect map is updated and the number of good LBAs are identified. The LBAs tested are moved from unprocessed space to processed space. The testing program is then updated to indicate that the flaw mapping test is complete.

Another automated test which may be performed while the disk drive is operating within the computer system is embedded runout compensation (ERC). Runout compensation relates to the ability to properly align the head of the read/write mechanism when reading or writing information from the spinning hard disk. This alignment is important so that information can be read accurately and/or stored properly. A problem commonly arises however in that the access and rotation of the disk in the disk drive is not precisely the same as the center of the concentric

tracks located on the disk. This lack of correspondence between the axis of rotation of the disk and the center of the concentric disk tracks result in a displacement of the head relative to the track center during the spinning or rotation of the disk.

In order to correct for any displacements, the misalignment may be measured and an error value generated which relates to the distance the head is away from the center of the track at a particular location on the track. These error values may be stored employed by the disk drive to provide alignment corrections for the head during the read/write process for a particular track on the disk. The processes employed during runout compensation to generate these error values are well known in the art and will not be described herein.

Disclosed in Fig. 5 is a flow chart which describes in detail the steps performed by the automated system when performing ERC. As was noted before, a first step (not shown) is the downloading and execution of a program which is either stored in ROM or on a processed area o the disk. A first query made in the automated test procedure is to whether a user command is pending for reading or writing information on the disk. If a user command is pending, the system will discontinue performing the automated test functions and perform the requested user commands. After the command is complete, and the system is back in idle mode the query will be made again.

If there are not user commands pending, a first query will be made as to whether there are any unprocessed tracks (cylinders) left to be tested. As in flaw mapping, the disk space may be broken up into three areas. The first (lower) is the process area which includes user LBAs. The second (middle) in the unprocessed area which does not contain user LBAs. The third (top) is the unprocessed area which also contains user LBAs. The processing for ERC is executed from lower to higher areas until all processing is complete. Since the ERC processor modifies the

path (straightens) of the heads, user data will not be moved to the process cylinder until the cylinder being tested (target) and target +1 cylinders have been processed. In order to perform the testing, a number of counters are employed. These include the last process user's cylinder as well as the last process cylinder. The last processed user cylinder indicates the last cylinder which has been processed which is available for storing data. The disk drive may be configured at the factory such that the last processed user cylinder equals -1 and the last process cylinder also equals -1.

Returning again to Fig. 5, if it is determined that there are unprocessed cylinders left, the last processed cylinder pointer is accessed to determine which cylinder is next to be processed. Once the next cylinder to be processed is identified, ERC is performed and the error information for that particular cylinder is stored in memory. After this information is generated the various pointers employed will also be updated. For example, the last processed cylinder is incremented up one as is the last processed user cylinder. This information is then saved in memory. The process then returns to start and if no user commands are pending the next unprocessed cylinder is processed.

Yet another automated process which may be performed once a hard drive is installed on a computer system is a final verification pass. The final verification pass is employed as a follow-up to the flaw mapping to confirm that the all the LBAs which were processed and shown to be without flaws, are able to be written to. The flowchart which describes steps performed in this final verification pass is disclosed in Fig. 6a-b. As an initial step, a query is made as to whether a user command is pending. If there is a user command pending, a further determination is made as to whether it is a read or write command. If it is a read command, the read function is performed without interruption and the automated program returns to its initial query. If it is a

write command, yet another query is made as to whether the write is to a processed or unprocessed area (with regards to the final verification test). If the write command is to a area which has been processed, the write function is performed without interruption and the program return to its initial query.

A query is then made as to whether the area to which write command is to be carried out includes any unprocessed LBAs. In particular, a query will be made as to whether all the writes are to an unprocessed area. If this is the case, each LBA to which a write is to occur has a write/verify test performed such as that described in Fig. 3. All LBAs which fail the write/verify will be re-assigned and a pointer provided on the media. Further, the flaw map will be updated to indicate the flawed LBAs. When the processing for particular increments of the disk drive is performed, the counter which tracks the LBAs which have been processed is updated by adding the processing increments. At this point, the automated program will return to the initial query.

If the area to which information is to be written contains both processed and unprocessed LBAs, all the writes are initially performed to the processed area. Once the unprocessed area is reached, the write/verify test is performed on all of the unprocessed LBAs. At this point, the LBAs which fail are reassigned and pointers are provided at the location. Further, the flaw map is updated as well as the counters which will provide indication of where the future cycles of the test are to begin.

Turning again to the first query of Fig. 6a, if there are no user commands pending, the final verification test program will then retrieve the stored information and counters which indicate where the write/verify test is to continue from. Typically, a predetermined processing increment is employed to identify the number of LBAs which will be tested during a particular cycle of the test. A first query made is to whether there are any LBAs left to process. If there

are not, the process ends. If there are LBAs to be processed, a further query is made as to whether there are enough LBAs in a normal processing increment. If there are not, this indicates that the end of the test is about to be reached, and as such the remaining LBAs are tested. In this situation, because information had been previously written to these LBAs either through the write/verification test and/or during normal operations this information is read from the particular LBA and is checked for accuracy. If an error is detected, the LBA is reassigned and a pointer provided. The flaw map is then updated and then the LBA pointer is also updated to indicate that all of the LBAs have been read during the final verification pass.

If it is determined that there are enough LBAs to fill a processing increment, the final verification test program will then perform the test such that the read verify function is performed on the LBAs in the increment as was described above. If any of the LBAs are shown to be flawed, the LBA is reassigned and the flaw map updated. Once the test for an increment is complete, the LBA counter which indicates which LBAs have been processed is incremented upwards. This information is then saved in memory and the test program returns to the initial query.

The foregoing description of the present invention has been presented for purposes of illustration and description. Furthermore, the description is not intended to limit the invention to the form disclosed herein. Consequently, variations and modifications commensurate with the above teachings, and the skill or knowledge of the relevant art, within the scope of the present invention. The embodiments described hereinabove are further intended to explain best modes known for practicing the invention and to enable others skilled in the art to utilize the invention in such, or other, embodiments and with various modifications required by the particular

applications or uses of the present invention. It is intended that the appended claims be construed to include alternative embodiments to the extent permitted by the prior art.